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Geotechnical investigation and testing — Field testing —

Part 16:
Borehole shear test

Reconnaissance et essais géotechniques — Essais en place —

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Foreword

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A list of all parts in the ISO 22476 series can be found on the ISO website.

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Introduction

The determination of the shear strength of soils is of paramount importance in geotechnical investigation and testing of soils. The shear resistance of soils and materials, characterised by the friction angle φ and the cohesion c, represents an important parameter for the geotechnical engineer while studying the stability of construction works and structures in relation with soils and materials. Usually, this resistance is measured in the laboratory using triaxial tests or direct shear tests carried out on field samples and only if sampling, conservation and preparation make it possible to consider the samples as non remolded and sufficiently representative of the soil in place.

Since the 1960's, various experimental devices have been designed and developed to determine the shear strength directly in situ from tests carried out in boreholes, in different soils at different depths.

The study of the bibliography literature shows that the majority of the existing borehole shear tests are based on the use of probes for applying and maintaining a normal pressure on the walls of the borehole and then to carry out a shear phase by a linear displacement of the probe on the soil against the walls of the borehole. The procedure is then repeated through a multistage increase of the normal pressure to obtain more values relating normal pressure and shear resistance.

The test equipment and apparatuses differ from each other by the geometry and size of the probes and by the shape of the friction part of these probes and by the procedure for applying normal pressure stages and shear phases.

One of the first devices of this kind is the Iowa Borehole Shear Tester (BST) developed in the USA.[13] The test is performed by placing a bilateral expandable probe, equipped with two diametrically opposed shear plates in a predrilled borehole, expanding the probe against the wall of the borehole and causing a shear failure in the soil by pulling the probe axially along the borehole. The size of the shear plates is relatively small (32,3 cm^2) and does not allow testing of soils with coarse elements, which can somewhat limit its field of application.

In the early 1970s, H. Mori,[15] in Japan, developed an in situ shearing device called the IST which was used in many projects. The principle of the test is carried out by generating a shearing force while pulling upwards a cylindrical expandable probe provided with teeth driven into the wall of the borehole but it is not reported whether the IST test continues to be performed currently.

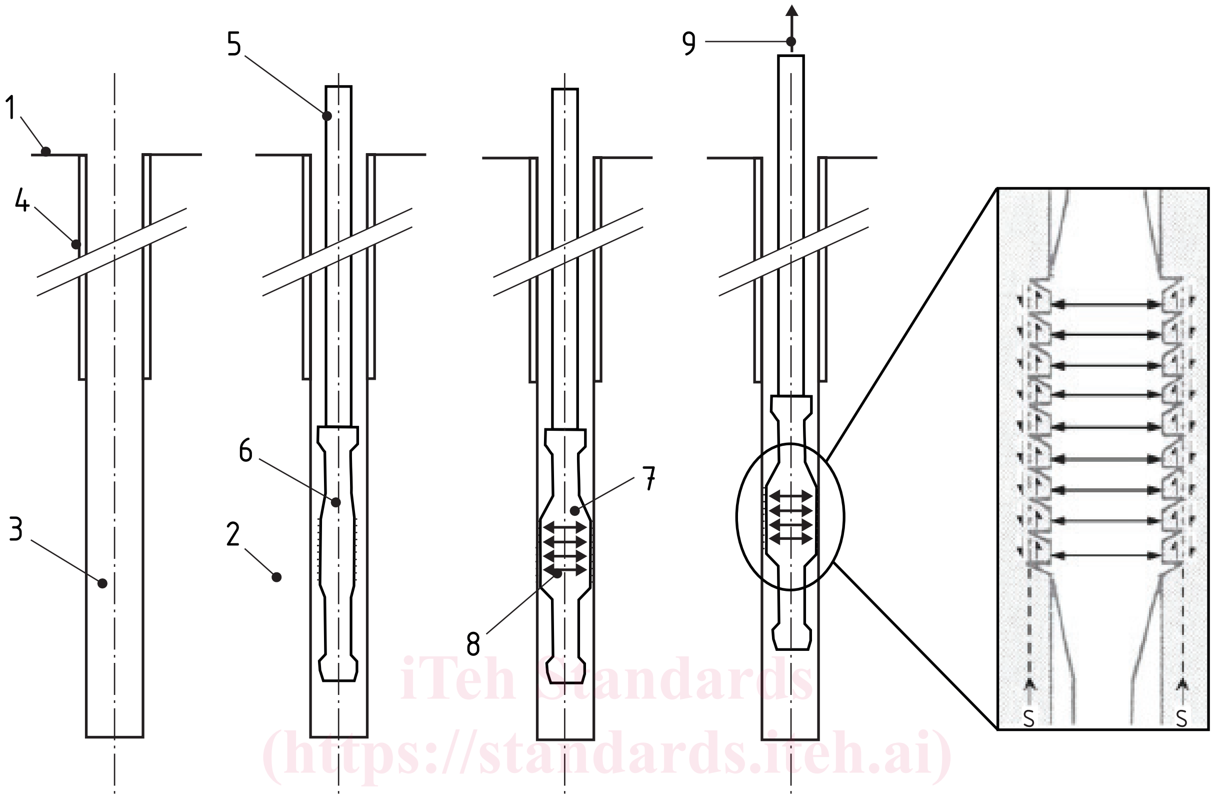
A self-boring in situ friction test (SBIFT), also developed in Japan,[14] allows the evaluation of soil characteristics as the initial horizontal at rest pressure, and deformation modulus and strength characteristics (cohesion and internal friction angle) of the soil. The SBIFT possesses a self-boring drilling functionality that can reduce the disturbance of the tested soil. However, very few data and results are available to currently validate this device and the characteristics of the soil it provides.

The same way as the SBIFT, a self-boring in situ shear pressuremeter (SBISP), was recently developed in China,[12] that allows the evaluation of pressuremetric characteristics as the initial horizontal at rest pressure, deformation yield pressure and modulus and also strength characteristics (cohesion and internal friction angle) of the soil. The SBISP possesses a self-boring drilling functionality that can greatly reduce the disturbance of the tested soil. However, very few data and results are available to currently validate this device and the characteristics of the soil it provides.

This document applies to the borehole shear test using the phicometer procedure, commonly named the phicometer borehole shear test (PBST). This test has been invented and developed by Gérard Philipponnat in the 1980's.[10]

This test has been the subject, between 1986 and 1992, of several applied research programs to design the apparatus and its components and to develop and optimize a common test procedure that can be used in a majority of soils. Various articles have been published as a result of these researches and since then PBST tests continue to be carried out currently, for the determination of the shear strength parameters from the test and to derive values for the undrained shear strength and an estimation of the drained effective shear resistance parameters.[9] The test has been standardized in France since 1997.

The borehole shear test using the phicometer covers a four-phases procedure consisting of drilling a borehole, lowering the probe to the test depth, inflating it into the borehole wall and shearing the soil by applying a series of steps of controlled radial pressure and simultaneously pulling out the probe with a constant displacement rate. The test sequences are shown in Figure 1.



a) Borehole drilling phase: drilling a phicometer borehole with casing (if necessary) and setting up the PBST test pocket in the borehole bottom

b) Probe placing phase: lowering the deflated probe to the test pocket depth

c) Teeth insertion phase: radial expansion of probe and insertion of the annular teeth in the borehole wall

d) Shearing phase: pulling on the probe inflated with a constant radial pressure at each multi-stage step

Key

1	ground surface	4	casing (if necessary)	7	probe (inflated state)
2	ground	5	string of rods	8	radial pressure
3	borehole	6	probe (deflated state)	9	pulling force
				S	cylindrical shear surface

Figure 1 — General arrangement and phases of the phicometer procedure borehole shear test

Geotechnical investigation and testing — Field testing —

Part 16:
Borehole shear test

1 Scope

This document is applicable to the borehole shear test using the phicometer procedure, commonly named the phicometer test (etymologically derived from phi for friction angle, co for cohesion and meter for measurement).

The test can be performed in all types of natural soils, fills and artificial soils, which can be saturated or not.

It does not apply to very soft fine soils, very loose coarse soils, medium strong to very strong rocks and natural or artificial soils with a predominance of cobbles having a particle diameter greater than 150 mm.

Generally, the test is applicable in soils with an order of magnitude of their in situ resistance characteristics as follows:

— Ménard pressuremeter limit pressure: 0,4 MPa < p_{lM} < 3,5 MPa approximately or more than 4 MPa in granular non-cohesive soils;

— CPT Cone resistance: 1,5 MPa <qc <15 MPa approximately, depending on the type of soil (see Annex E);

— SPT N: 8 <N <50 approximately, depending on the type of soil (see Annex E).

The test can also be carried out in soils presenting a resistance outside these application limits as long as the representativeness of the results is assessed or validated by the analysis of the PBST graphs (see Clause 8).

This document applies only to tests carried out at a depth less than or equal to 30 m.

The parameters derived from this test are the shear strength properties, as the cohesion and angle of friction.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10012, *Measurement management systems — Requirements for measurement processes and measuring equipment*

ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for the sampling of soil, rock and groundwater*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1.1
borehole shear test

process during which a special shearing probe is installed in a borehole at a defined depth and inflated against the borehole wall and pulled to determine the resulting shear resistance of the soil

Note 1 to entry: This process is repeated with a succession of increased maintained normal pressure steps so as to obtain a pressure versus shear stress relation of the soil.

3.1.2
phicometer borehole shear test

PBST

shear test performed in a *phicometer borehole* (3.1.4) with the *phicometer probe* (3.1.6) and the phicometer test procedure

Note 1 to entry: See Clause 5 for the phicometer test procedure.

3.1.3
phicometer

whole equipment which is used to carry out a *phicometer borehole shear test* (3.1.2)

3.1.4
phicometer borehole

part of a borehole in which the *phicometer test pocket* (3.1.5) is to be set up

Note 1 to entry: See 5.2.

3.1.5
phicometer test pocket

cylindrical cavity with a circular section made in a borehole and in which the *phicometer probe* (3.1.6) is placed, brought into contact and pulled upwards during the test phases

3.1.6
phicometer probe

cylindrical expandable probe with annular shearing teeth, used to carry out a *phicometer borehole shear test* (3.1.2)

Note 1 to entry: See 4.2 and Figure 3.

3.1.7
phicometer test diagram

set of plots resulting from the *PBST* (3.1.2) test and allowing the determination of the shear resistance of the soil

Note 1 to entry: See Clause 8 and Figure 6.

3.1.8
phicometer cohesion

in situ cohesion c_i obtained from the *phicometer test diagram* (3.1.7)

3.1.9
phicometer angle of friction

in situ angle of shear friction φ_i obtained from the *phicometer test diagram* (3.1.7)

3.1.10
depth of test

distance between the ground level and the centre of the shearing zone of the phicometer probe measured along the borehole axis

3.1.11
operator
technician trained in carrying out PBST tests, in accordance with this document

3.2 Symbols

For the purposes of this document, the symbols of Table 1 apply.

Table 1 — Symbols

Symbol	Description	Unit
T	Pulling force on the probe	kN
T_l	Maximum pulling force	kN
V	Volume injected into the measuring cell of the probe as read on the control unit	cm^3
V_d	Volume injected into the measuring cell of the probe at the beginning of the application of the pulling force ($V_d = V_{60}$)	cm^3
V_f	Volume injected into the measuring cell of the probe at the end of the application of pulling force	cm^3
V_{30}	Volume injected into the measuring cell of the probe after 30 s under a constant pressure phase	cm^3
V_{60}	Volume injected into the measuring cell of the probe after 60 s under a constant pressure phase	cm^3
d_{s0}	Initial diameter of the probe at rest in the shearing zone (see Figure 3)	mm
c_i	phicometer cohesion measured in situ by the PBST	kPa
d_s	Diameter of the probe in the shearing zone after injection of a volume V (see Figure 3)	mm
d_t	Diameter of the pocket at the level of the test	mm
d_c	Outside diameter of the measuring cell of the probe	mm
l_t	Slots length of the expansible shear tube	mm
l_c	Distance between the rings of the measuring cell of the probe	mm
l_s	Conventional length of the shearing zone (see Figure 3)	mm
N	Standard penetration test SPT Blow count (see ISO 22476-3)	-
p_c	Conventional radial pressure applied to the ground after corrections	kPa
p_e	Probe stiffness pressure loss determined by calibration	kPa
p_h	Pressure due to the injection liquid column in the probe (between z_c and z_s)	kPa
p_{lM}	Ménard pressuremeter limit pressure (see ISO 22476-4)	MPa
p_r	Pressure of the liquid injected into the phicometer measuring cell, read at the level z_c of the control unit (CU)	kPa
p_z	Pressure of the liquid at the centre of the measuring cell	kPa
q_c	Cone penetration resistance (see ISO 22476-1 or ISO 22476-12)	MPa
t	Time	s
v	Rate of axial displacement of the probe during the pulling phase	mm/min
z	Elevation, ascending above datum	m
z_0	Elevation of the ground surface level at the location of the test	m
z_c	Elevation of the pressure measuring device of the liquid injected into the phicometer measuring cell	m
z_e	Elevation of the drilling fluid in the borehole	m
z_{ei}	Initial level of water or mud measured in the borehole before the beginning of the test	m

Table 1 *(continued)*

Symbol	Description	Unit
z_{ef}	Final level of water or mud measured in the borehole after the end of the test	m
z_s	Elevation of the centre of the shearing zone of the phicometer probe at the beginning of the test	m
z_w	Elevation of the ground water table (or free water surface in a marine or river environment)	m
γ_l	Unit weight of the liquid injected into the measuring cell	kN/m^3
γ_w	Unit weight of water	kN/m^3
Δl	Axial displacement of the probe during shearing	mm
Δp	Loading pressure increment	kPa
Δt	Duration of a pressure hold at a loading stage	s
Δt_p	Duration of a loading pressure hold during the preliminary phase	s
ΔV	Injected volume change from 30 s to 60 s after reaching the pressure hold	cm^3
φ_i	Phicometer angle of friction measured in situ with the phicometer borehole shear test	°
τ	Shear stress	kPa
τ_l	Conventional limit shear stress	kPa

4 Equipment

4.1 General

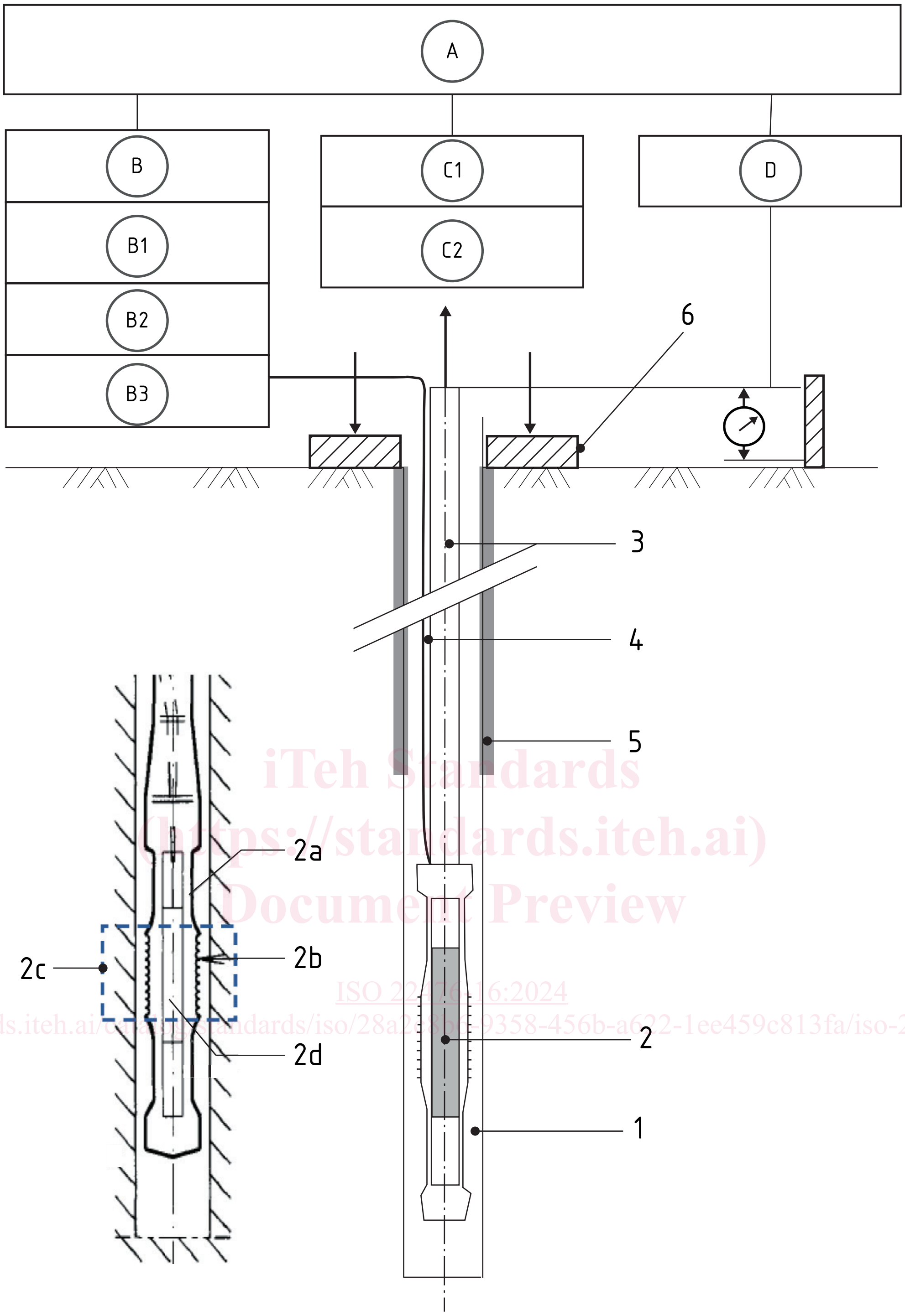
The equipment to carry out phicometer borehole shear tests shall consist of the following components:

- phicometer probe,
- pressure – volume control unit (CU),
- a line to connect the probe to the CU,
- a pulling device placed on a reaction base on the ground surface and linked to the probe with pulling rods,
- a device to control the axial shearing displacement rate,
- means of measurement and display of pressure, volume, pulling force, axial displacement and the external diameter of the shearing zone of the probe.

The equipment can also include a data logger.

A phicometer borehole shear test (PBST) device assembly is shown in Figure 2.

An example of installation of the PBST equipment is shown in Annex H.



Key

1	borehole	3	string of rods	5	borehole casing (if necessary)
2	phicometer probe	4	connecting line	6	reaction base
		2a	expansible slotted tube	2c	shearing zone mobilized by the probe teeth
		2b	annular teeth	2d	inflatable measuring cell
A	data logger (optional)	B2	volume measurement	C2	pulling device with timer
B	pressure-volume control unit (CU)	B3	display of readings	D	axial displacement control
B1	pressure regulator & injection device	C1	measurement of pulling force		

Figure 2 — Diagram of the PBST test device assembly and its components

4.2 Phicometer probe

The phicometer probe is shown in Figure 3. It consists of a steel slotted device, called “expandable slotted shear tube” in which a radially expandable cylindrical cell called “measuring cell” is placed.

The expandable slotted shear tube is a hollow steel cylinder rigidly connected to the pulling rods to ensure its operation and to transmit the pulling force to the probe from the surface of the ground. It is designed with different parts featuring:

- a central shearing zone, made up of six initially jointed rigid plates, parallel to the axis of the probe and comprising ten annular teeth, regularly spaced vertically;
- two guard zones, made up of metal strips acting as a spring;
- an inflatable measuring cell placed at the level of the central shearing zone inside the expandable slotted shear tube and which is composed of a steel core, a deformable flexible membrane and a tube for liquid injection used to inflate this cell and to measure its volume.

The characteristics of the probe shall be as given in Annex A. Two types of deformable flexible rubber membranes exist:

- a standard membrane;
- a reinforced membrane.

The standard membrane is used for all soil types.

The reinforced membrane is exclusively used for aggressive soils where damaging and bursting of the cell probe occurs frequently.

4.3 Connection tube line and pulling rods

4.3.1 Connection tube line

The flexible tube line connecting the pressure volume control unit to the probe is used to inject the fluid in the measuring cell.

The expansion coefficient of this line shall be lower than 0,1 cm^3/MPa per meter of line.

4.3.2 Pulling rods

A string of steel rods connects the probe to the equipment placed on the ground surface. The resistance of this string of rods shall withstand the efforts and stresses generated by the test during all its phases.

The elongation of the drill string shall remain less than 0,05 % of its total length.

The section of the rods and their fittings shall allow free sliding of the drill string in the borehole.

The part of the pulling rods above the ground surface is threaded over all its length, to allow the adjustment of the locking system of the string of rods on the pulling device (see 4.4.1).